CHAPTER 3

STRENGTH AND SERVICEABILITY REQUIREMENTS

3-1. General

a. All reinforced-concrete hydraulic structures must satisfy both strength and serviceability requirements. In the strength design method, this is accomplished by multiplying the service loads by appropriate load factors and by a hydraulic factor, H_f. The hydraulic factor is applied to the overall load factor equations for obtaining the required nominal strength. The hydraulic factor is used to improve crack control in hydraulic structures by increasing reinforcement requirements, thereby reducing steel stresses at service load levels.

b. Two methods are available for determining the factored moments, shears, and thrusts for designing hydraulic structures by the strength design method. They are the single load factor method and a method based on the ACI 318 Building Code. Both methods are described herein.

c. In addition to strength and serviceability requirements, many hydraulic structures must also satisfy stability requirements under various loading and foundation conditions. The loads from stability analyses that are used to design structural components by the strength design method must be obtained as prescribed herein to assure correctness of application.

3-2. Stability Analysis

a. The stability analysis of structures, such as retaining walls, must be performed using unfactored loads. The unfactored loads and the resulting reactions are then used to determine the unfactored moments, shears, and thrusts at critical sections of the structure. The unfactored moments, shears, and thrusts are then multiplied by the appropriate load factors, and the hydraulic factor when appropriate, to determine the required strengths which, in turn, are used to establish the required section properties.

b. The single load factor method must be used when the loads on the structural component being analyzed include reactions from a soil-structure interaction stability analysis, such as footings for walls. For simplicity and ease of application, this method should generally be used for all elements of such structures. The load factor method based on the ACI 318 Building Code may be used for some elements of the structure, but must be used with caution to assure that the load combinations do not produce unconservative results.

3-3. Required Strength

Reinforced-concrete hydraulic structures and hydraulic structural members shall be designed to have a required strength, U_h, to resist dead and live loads in accordance with the following provisions. The hydraulic factor is to be applied in the determination of required nominal strength for all combinations of axial load and moment, as well as for diagonal tension (shear). However, the required design strength for reinforcement in diagonal tension (shear) should be calculated by applying a hydraulic factor of 1.3 to the excess shear. Excess shear is defined as the difference between the factored shear force at the section, V_u, and the shear strength provided by the concrete, ϕV_c. Thus $\phi V_s \geq 1.3\ (V_u - \phi V_c)$, where ϕV_s is the design capacity of the shear reinforcement.

a. Single load factor method. In the single load factor method, both the dead and live loads are multiplied by the same load factor.

$$U = 1.7(D + L) \tag{3-1}$$

where

D = internal forces and moments from dead loads of the concrete members only

L = internal forces and moments from live loads (loads other than the dead load of the concrete member)

For hydraulic structures, the basic load factor is then multiplied by a hydraulic factor, H_f.

$$U_h = H_f(U) \tag{3-2}$$

where H_f = 1.3 for hydraulic structures, except for members in direct tension. For members in direct tension, H_f = 1.65. Other values may be used subject to consultation with and approval by CECW-ED.

Therefore, the required strength U_h to resist dead and live loads shall be at least equal to

$$U_h = 1.7H_f(D + L) \tag{3-3}$$

An exception to the above occurs when resistance to the effects of wind or other forces that constitute short duration loads with low probability of occurrence are included in the design. For that case, the following loading combination should be used:

$$U_h = 0.75\left[1.7H_f(D + L)\right] \tag{3-4}$$

b. Modified ACI 318 Building Code Method. The load factors prescribed in ACI 318 may be applied directly to hydraulic structures with two modifications. The load factor for lateral fluid pressure, F, should be taken as 1.7. The factored load combinations for total factored design load, U, as prescribed in ACI 318 shall be increased by the hydraulic factor $H_f = 1.3$, except for members in direct tension. For members in direct tension, $H_f = 1.65$.

The equations for required strength can be expressed as

$$U_h = 1.3U \tag{3-5}$$

except for members in direct tension where

$$U_h = 1.65(U) \tag{3-6}$$

For certain hydraulic structures such as U-frame locks and U-frame channels, the live load can have a relieving effect on the factored load combination used to determine the total factored load effects (shears, thrusts, and moments). In this case, the combination of factored dead and live loads with a live load factor of unity should be investigated and reported in the design documents.

c. Earthquake effects. If a resistance to specified earthquake loads or forces, E, are included, the following combinations shall apply.

(1) Unusual

(a) Nonsite-specific ground motion design earthquake (OBE)

$$U_h = 1.7(D + L) + 1.9E \tag{3-7}$$

(b) Site-specific ground motion for design earthquake with time-history and response spectrim analysis (OBE)

$$U_h = 1.4(D+L) + 1.5E \tag{3-8}$$

(2) Extreme

(a) Nonsite-specific ground motion (MCE)

$$U_h = 1.1(D + L) + 1.25E \tag{3-9}$$

(b) Site-specific ground motion (MCE)

$$U_h = 1.0(D + L + E) \quad (3\text{-}10)$$

d. Nonhydraulic structures. Reinforced concrete structures and structural members that are not classified as hydraulic shall be designed with the above guidance, except that the hydraulic factor shall not be used.

3-4. Design Strength of Reinforcement

a. Design should normally be based on 60,000 psi, the yield strength of ASTM Grade 60 reinforcement. Other grades may be used, subject to the provisions of paragraphs 2-2 and 3-4.b. The yield strength used in the design shall be indicated on the drawings.

b. Reinforcement with a yield strength in excess of 60,000 psi shall not be used unless a detailed investigation of ductility and serviceability requirements is conducted in consultation with and approved by CECW-ED.

3-5. Maximum Tension Reinforcement

a. For singly reinforced flexural members, and for members subject to combined flexure and compressive axial load when the axial load strength ϕPn is less than the smaller of $0.10 f'_c A_g$ or ϕPb, the ratio of tension reinforcement ρ provided shall conform to the following.

(1) Recommended limit = 0.25 ρ_b.

(2) Maximum permitted upper limit not requiring special study or investigation = 0.375 ρ_b. Values above 0.375 ρ_b will require consideration of serviceability, constructibility, and economy.

(3) Maximum permitted upper limit when excessive deflections are not predicted when using the method specified in ACI 318 or other methods that predict deformations in substantial agreement with the results of comprehensive tests = 0.50 ρ_b.

(4) Reinforcement ratios above 0.5 ρ_b shall only be permitted if a detailed investigation of serviceability requirements, including computation of deflections, is conducted in consultation with and approved by CECW-ED. Under no circumstance shall the reinforcement ratio exceed 0.75 ρ_b.

b. Use of compression reinforcement shall be in accordance with provisions of ACI 318.

3-6. Control of Deflections and Cracking

a. Cracking and deflections due to service loads need not be investigated if the limits on the design strength and ratio of the reinforcement specified in paragraphs 3-4.a and 3-5.a(3) are not exceeded.

b. For design strengths and ratios of reinforcement exceeding the limits specified in paragraphs 3-4.a and 3-5.a(3), extensive investigations of deformations and cracking due to service loads should be made in consultation with CECW-ED. These investigations should include laboratory tests of materials and models, analytical studies, special construction procedures, possible measures for crack control, etc. Deflections and crack widths should be limited to levels which will not adversely affect the operation, maintenance, performance, or appearance of that particular structure.

3-7. Minimum Thickness of Walls

Walls with height greater than 10 feet shall be a minimum of 12 inches thick and shall contain reinforcement in both faces.